GPG018

Good Practice Guide

Reducing energy consumption costs by steam metering

CARBON TRUST

Making business sense of climate change

Contents

The Carbon Trust gratefully acknowledges Spirax Sarco*, Solatron Mobrey, the Combustion Engineering Association and all other organisations that contributed to this guide.

1 Introduction

This guide is intended to help plant engineers who wish to save energy through measuring and controlling steam used for process and/or space heating.

Owing to the increasing need to monitor energy use and plant efficiency to reduce operating costs and carbon emissions, the number of steam meters installed is expected to rise. Therefore, it is important that informed decisions are made when selecting new and/or replacement instruments.

The guide explains why it is important to meter steam and why the properties of steam need to be considered when measuring steam flow. It describes the operating principles of the various types of steam meter and the associated instrumentation that translates information from the meter into a usable form. The factors affecting the selection of an appropriate steam meter for a particular application are considered and the principles of correct installation are outlined.

This guide will provide energy and plant managers with an understanding of how steam metering provides the knowledge of steam use essential for energy efficiency and carbon savings.

1.1 What is steam?

Steam is produced when water boils. Under normal atmospheric conditions, water boils at 100ºC. At higher pressures, however, the boiling point increases. For example, a typical steam boiler working at 1,000kPa (10 bar) releases steam at 184ºC. Comprehensive data on the properties of steam are given in steam tables, which are widely available on the Internet or in textbooks.

The heat applied to increase the temperature of water is called 'sensible heat'. Sensible heat can continue to be applied until water reaches its boiling point. Substantial further input of heat – known as 'latent heat' – is then required to cause the liquid water to evaporate into gaseous steam. This change in state occurs without any change in temperature.

The steam produced is heat saturated, and is commonly known as saturated steam. The steam and the water are in equilibrium (i.e. the addition of more heat into the water at that pressure does not increase the temperature of the steam).

The latent heat required to boil water at atmospheric pressure is 2,257kJ/kg but, at 1,000kPa gauge(g) (10bar(g)), it is only 2,000kJ/kg. However, the production of steam at 1,000kPa(g) first requires the water to be heated to 184ºC rather than 100ºC; this will require an additional sensible heat input of 363kJ/kg.

Process applications normally demand a supply of saturated steam. When saturated steam is delivered into, for example, a heat exchanger, heat energy is transferred from the steam into the product that is to be heated. The heat surrendered by the steam is the latent heat. Just as water is converted to steam without a change in temperature, so does steam condense without a change in temperature. The condensate formed when steam condenses contains no further energy that can be used by the process. It is therefore released through a steam trap and, where practicable, is returned to the boiler plant where it may be re-used.[1]

Although heating water will not increase the temperature of the steam formed, it is possible to apply further heat energy to saturated steam in a separate heat exchanger. This causes an increase in the temperature of the steam and it becomes 'superheated'. Unless extremes of temperature are required, superheated steam is rarely used for heating purposes. This is because high rates of heat transfer are not possible because the superheated steam must first surrender heat through a reduction in temperature. Only once it has cooled to saturated conditions does it yield up its substantial latent heat through condensation. Therefore, superheated steam is mainly used in applications such as steam turbines.

1.2 What is steam used for?

Steam is used as an indirect medium for process and space heating, or for direct use for sterilisation and humidification. It is favoured as a heating medium because of its controllability. Another advantage of steam is that it provides a high rate of heat transfer at a relatively low temperature.

Steam is widely used in food processing, beverage production and brewing, as well as in pharmaceutical and petrochemical processes. In all these applications, steam does not come into direct contact with the product being heated, but is contained within some form of heat exchanger.

[1] For information on steam traps and condensate recovery, see GPG382 *Energy efficient operation of heat distribution systems*

Steam can also come into direct contact with product (e.g. in sterilisers and autoclaves) and it is invaluable for finishing and pressing clothing following manufacture or cleaning. There is increasing demand for humidification systems in modern buildings, which often require steam to be injected into the air handling units.

In most of these applications, steam is produced in a separate boiler. The boiler may be dedicated to an individual application, but it is more usual to have centralised boiler plant supplying steam to all users on a site. Steam meters are commonly used to:

- Measure the steam exported from a centralised boilerhouse
- Measure the supply to individual processes, which may operate as individual cost centres.

1.3 Why measure steam flow?

You can't control what you don't measure

The need to measure steam flow is not always fully appreciated. Steam is an energy medium, so measuring steam flow is actually measuring a flow of energy. In the same way that other energy flows are metered (e.g. gas, oil and electricity), measuring the steam flow to an entire factory allows trends in energy use to be established, making it easier to identify opportunities for cost and carbon savings. The extent of the carbon savings achieved by reducing energy use for steam will depend on the fuel used to raise the steam.[2]

Many larger organisations divide their operations into individual cost centres. By metering the flow of steam into these individual areas, energy costs can be monitored more closely. Steam measurements may also help to develop maintenance regimes.

The additional tax on energy consumption imposed by the Climate Change Levy makes it essential to monitor energy use both to control consumption and to identify areas for potential savings. Identifying areas where energy could be saved will enable companies to focus their efforts to reduce operating costs by using energy more efficiently. This is particularly true for companies in energy-intensive sectors that need to meet challenging energy efficiency targets to continue to receive the 80% discount on Levy payments available to participants in a Climate Change Agreement (CCA) negotiated with the Government by their trade body.

The Carbon Trust has a number of free guides offering practical advice on reducing steam costs. These include:

- ECG066 *Steam generation costs*
- GIR092 *Steam distribution costs*
- GPG369 *Energy efficient operation of boilers*
- GPG382 *Energy efficient operation of heat distribution systems.*

To obtain copies, call the Carbon Trust Energy Helpline on 0800 58 57 94 or visit the website (www.thecarbontrust.co.uk/energy).

Tax breaks when buying listed energy efficient equipment

The Energy Technology List is designed for companies and organisations wishing to buy energy efficient equipment, and details over 6,200 products that meet Government-prescribed energy efficiency criteria. A key feature of the Energy Technology List is that it provides details of specific equipment and suppliers.

Investment in products listed on the Energy Technology List may also qualify for an Enhanced Capital Allowance (ECA), a tax relief permitting businesses to deduct 100% of capital expenditure against their taxable profits in the first year. Qualifying expenditure can include the cost of buying the equipment as well as the cost of installation and transporting the equipment to the site.

For the latest information about the Energy Technology List and ECAs, visit www.eca.gov.uk or call the Carbon Trust Energy Helpline on 0800 58 57 94.

[2] Conversion factors to convert energy consumed in kWh to kg of carbon dioxide for a selection of common fuels are given in FL132 *Energy and carbon conversions* or in the Resources area of the Carbon Trust Energy website (www.thecarbontrust.co.uk/energy).

2 Measuring steam flow

A steam flow meter usually consists of two components:

- A primary element – the metering unit which is placed in the flow stream (see Section 5)
- A secondary element – a device that translates the data from the primary element into a format that can be communicated to other instruments (see Section 6).

Steam is conveyed from the boiler to a process application through an insulated piping system. But because no insulation system can be 100% efficient, there will be some heat loss. This heat loss will result in the condensation of a small proportion of the steam. This condensate needs to be released from the steam system using steam traps located at various points in the system.

The objective of steam metering is to measure available energy flow (i.e. steam only and not steam plus condensate). A kilogram of steam will produce a kilogram of condensate, but the aim is to measure steam only. Thus, a metering system that measures total mass flow is of little value when seeking to measure available energy, as this would include condensate. Because this has no latent heat, its inclusion gives an artificially high measurement of energy flow.

A system whose operating principle is based on the measurement of volumetric flow gives much more meaningful results because any condensate present is largely ignored. Condensate occupies a tiny fraction of the volume of steam; for example, in a 1,000kPa (10 bar) steam system, 1kg of steam occupies 177 litres whereas it condenses to occupy just one litre. A small proportion of condensate therefore has a minor effect on the accuracy of a meter measuring volumetric flow.

However, to be of practicable value, the volumetric flow needs to be converted to mass flow units (e.g. kg/hour). This is because the heat content of steam is directly related to its mass. In addition, most steam systems incorporate pressure-reducing valves (PRVs). In such systems, it is impracticable to discuss volumetric flow because, for a given mass flow (and indeed energy flow), the volume flow varies from one section of the piping system to another.

Most steam flow meters measure volume flow. This is generally converted into the equivalent mass flow by the flow computer (see Section 6.2) recording the steam data, which calculates the corresponding steam mass flow rate from the measured steam volume flow and the steam pressure. If the steam pressure is not measured as part of the metering method, a separate pressure transducer is required.

Measuring the temperature as well gives optimum accuracy, but this adds cost and cannot always be justified for saturated steam. However, it should be measured when dealing with superheated steam, in which case, the temperature measurements should also be fed to the flow computer.

Many flow computers display more than just an instantaneous mass flow rate (e.g. in kg/hour). A totalised flow can usually also be recorded. Data from the flow computer can be sent to a building management system, to a monitoring and targeting (M&T) system or simply to a data logger. This allows a record of steam consumption to be built up over a period of days, weeks or years.

3 Steam quality

Four properties of steam influence the accuracy and, in some cases, the life of a meter. These are:

- Dryness fraction of the steam
- Presence of air or non-condensable gases
- Pressure of the steam
- Temperature of the steam.

Steam quality affects the accuracy and life of a steam meter.

3.1 Dryness fraction

This quality is important in the case of saturated steam, which usually contains a significant proportion of water droplets in suspension. Because the water contains no latent heat, the steam has a much reduced level of latent heat. The ideal condition of 100% dryness means that the steam contains no moisture and, therefore, the maximum possible amount of heat is available. In practice, the steam being measured is unlikely to be 100% dry; anything better than 95%[3] is accepted as a low dryness fraction for the purposes of steam metering.

Figure 1 shows wet steam (representative of perhaps only 85% dryness fraction). There is a substantial layer of condensate on the pipe wall and significant entrained moisture within the volume of the steam. This high concentration of moisture is unsatisfactory because it has no useful heat energy. Use of a steam separator (see Section 8) to remove much of this moisture and condensate improves the steam dryness fraction (see Figure 2).

Continuous measurement of dryness fraction is impracticable in most instances and most steam flow computers have the facility to input an assumed value.

Figure 1 *Steam pipe steam conditions without a steam separator and trap*

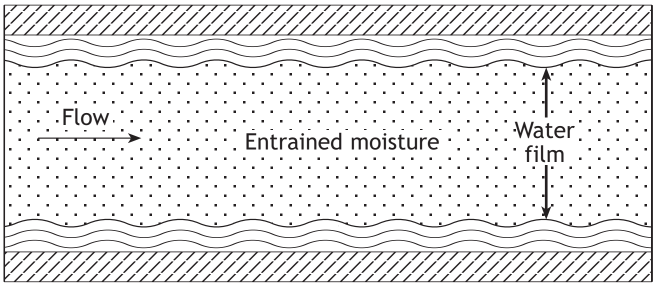
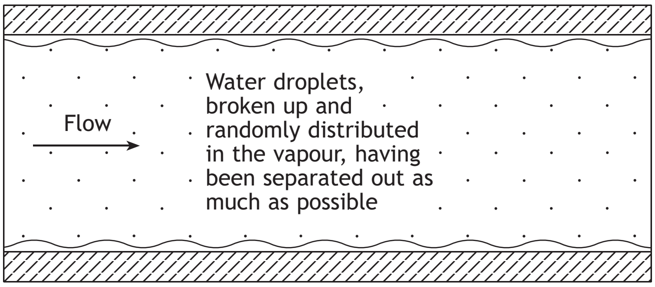


Figure 2 *Steam pipe conditions with a steam separator and trap*



3.2 Presence of air or non-condensable gases

The ability of water to absorb air decreases with increasing temperature; hence, air may be released within the boiler, which it leaves with the steam. Such gases present two problems to the steam process:

- Because air is a good heat insulator, any pockets of air in the process equipment will inhibit the transfer of heat
- The reduced temperature of the steam. Dalton's law of partial pressures[4] means that if steam pressure is measured at 1,000kPa (10 bar), but the 'steam' actually consists of 95% saturated steam and 5% air, the total pressure is made up of 950kPa (9.5 bar) steam pressure and 50kPa (0.5 bar) air pressure. Steam at 950kPa has a temperature of 182°C, rather than the 184°C of steam at 1,000kPa.

[3] If the water content of the steam is 5% by mass, then the steam is said to be 95% dry.
[4] Accurate application of this law requires measurement in absolute pressure rather than gauge pressure.

Three actions can be taken to remove non-condensable gases from a steam system:

- Use an oxygen scavenger chemical during water treatment
- Heat the feedwater tank to 90ºC or more to substantially reduce the dissolved oxygen content of the water (the ideal temperature is 107ºC, but this requires the greater expense of a pressurised de-aerator)
- Fit an automatic air vent to the steam system in parallel with the manual air vent valve fitted to most steam boilers. Many steam traps incorporate thermostatic air vents.

Effective water treatment and the use of air eliminators on the boiler plant can mitigate the problem of non-condensable gases to a degree that it can be neglected, except for highly specialised applications.

3.3 Pressure and temperature compensation

Most steam meters measure the volumetric flow of the gas (i.e. steam) flowing through them (see Section 2). Because steam is compressible, reducing its pressure necessarily decreases its density, and vice-versa. Therefore, it is important to know the pressure of the steam to be able to convert the volume flow into a mass flow.

A significant reduction in the pressure of saturated steam can cause the temporary formation of superheated steam. For example, if 1,000kPa (10 bar) steam at 184ºC is reduced to 400kPa (4 bar), it becomes superheated steam because the saturation temperature of 400kPa steam is only 152ºC.

Most steam meters need to be augmented with pressure measurement so that variations in steam pressure can be compensated for. In the case of saturated steam, the correlation between pressure and temperature means that the pressure can be calculated from the temperature measurement.

If the steam is known to be in superheated condition, it is essential to measure the temperature to facilitate compensation. Such compensation is also desirable if very accurate steam metering is required.

Variations in pressure and temperature can cause significant inaccuracies in the meter reading. Always consider the need to compensate for these factors.

4 Criteria for steam meter selection

The following are important when choosing a steam flow meter:

- Accuracy
- Repeatability
- Turndown ratio
- Frequency of recalibration
- Ease of installation
- Installation and maintenance costs.

It is virtually impossible to design a meter that optimally satisfies all these criteria and, in virtually all cases, it is necessary to select a system that forms the most appropriate compromise. These criteria feature in the summary table in Section 7 on the selection of a suitable steam flow meter.

Specific application needs will influence the choice of meter.

4.1 Accuracy

Accuracy is often the foremost consideration for plant engineers. No meter is 100% accurate and it is important to remember that the accuracy of a steam meter can be affected by both the quality of the steam and the installation. Steam quality is discussed in Section 3. Steam meters usually require a certain length of straight pipe both upstream and downstream (see Section 8), though some models can, to some extent, calculate and compensate for the error caused by undesirable installations.

To achieve accurate readings, always follow the manufacturer's instructions on installation.

To obtain the most accurate results from a steam meter, it is necessary to ensure that:

- The steam quality is as good as is practicable
- The steam meter is installed strictly according to the manufacturer's recommendations.

There are two ways of describing the accuracy of a steam meter and it is important to distinguish between them. Accuracy can be expressed as:

- Percentage of the measured value or actual reading (i.e. a given flow rate)
- Percentage of the full scale deflection (FSD) of the meter.

The difference is best illustrated with an example. Consider a steam meter with a range of 100–1,000kg/hour that is used in an application where the flow varies between 200kg/hour and 800kg/hour. If the meter is accurate to within ±5%, then for a measured flow of 200kg/hour, the actual flow will be between ±5% of 200kg/hour (i.e. 190–210kg/hour). And at a displayed value of 800kg/hour, the true value will be between 760 and 840kg/hour. However, the situation is very different if the accuracy is relative to FSD; for example, a quoted accuracy ±5% of FSD means ±5% of the 1,000kg/hour maximum for the meter. This means that any reading could be accurate to ±50kg/hour at any point in the meter's operating range. Thus, a displayed reading of 200kg/hour could actually represent a true flow of anywhere between 150kg/hour and 250kg/hour.

Fortunately, most meters are much more accurate than ±5% of FSD. However, this example demonstrates how important it is to discriminate between an accuracy based on an actual reading and one based on FSD.

4.2 Repeatability

The repeatability of a meter is its ability to indicate the same value for an identical flow rate on two or more successive occasions. Although a steam meter may provide almost perfect results when it has just been commissioned, it is essential that future measurements will be consistent.

Steam is an erosive medium. Meters whose accuracy relies on their precise geometry may suffer from erosion due to the long-term effects of steam flow. Meters that employ moving parts are subject to mechanical wear and their accuracy will deteriorate with time. Changes in frictional characteristics between components can also cause these to adopt differing behaviour under identical flow conditions, leading to inconsistent results.

4.3 Turndown ratio

All steam meters have stipulated maximum and minimum flow limits beyond which their accuracy and/or repeatability will deteriorate. The turndown ratio is a means of describing the span of flow rates over which a meter will work within given tolerances of accuracy and repeatability. For example, a meter that can measure accurately from 1,000kg/hour to 30,000kg/hour has a turndown ratio of 30:1 (i.e. maximum flow:minimum flow). Turndown ratio is also referred to as effective range or rangeability.

The turndown ratio quoted by the manufacturer does not necessarily mean that the meter will provide that full turndown ratio on a specific application. Again, this is best illustrated with an example. Consider a meter having a turndown ratio of 30:1 and a maximum flow limit of 30,000kg/hour; this means it can read accurately from 1,000kg/hour to 30,000kg/hour. However, if this meter is installed where the maximum flow is only ever 20,000kg/hour, its turndown ratio effectively becomes only 20:1. This example highlights the importance of assessing the likely flow parameters before choosing a meter. In some cases, it may be necessary to install a meter that is smaller than the pipe size to optimise the available turndown ratio by increasing the flow velocity as it approaches the meter. It should be remembered that increasing velocity to give turndown will be at the expense of pressure drop and is, therefore, an energy cost.

A metering system is sometimes provided with a low-flow cut-off such that, below a certain flow rate, all readings are interpreted as zero rather than a very inaccurate low value. In many practical applications, the steam flow rate is low for considerable periods, so a small meter turndown can result in a serious error in a cumulative total.

If the flow parameters are uncertain, a high turndown ratio is essential.

4.4 Frequency of recalibration

Some steam meters require periodic recalibration. Other designs are calibrated at the factory and never require recalibration. Although it is desirable to avoid the cost and inconvenience of recalibration, other factors (e.g. feasibility of installation, cost or desire for a high turndown ratio) may override this when selecting a meter.

Frequency of recalibration also depends on the application. For example, a high level of confidence is essential where meters are used for financial monitoring. Such meters require more frequent recalibration than, say, a simple trend meter.

It is also important to consider how the steam system might operate while the meter is removed for recalibration. For example, is bypass pipework necessary to, perhaps, facilitate the installation of another meter? Figure 14 in Section 8 shows a typical installation of a steam meter that allows for its removal for recalibration.

Recalibration and maintenance costs form an important element of whole-life costing of a steam meter.

4.5 Ease of installation

Meters come in many shapes and sizes, and it is not practicable for every type to be considered for an application. The weight and/or size of some models may preclude their use in certain circumstances. Another consideration is the length of straight pipe required upstream and downstream of the meter to achieve accurate and repeatable measurements.

Ease of installation is an important consideration for existing systems.

4.6 Cost of installation and maintenance

A low-cost meter is not always the best long-term choice. In addition to the purchase price of the meter itself, it is necessary to consider the need for additional pressure and temperature sensors, and a flow computer or other data-recording equipment. The true installed cost also includes the work needed to physically incorporate the meter into the piping system. This can range from a simple connection into the pipe or a major pipework modification.

It is also important to consider the cost of maintenance. This is usually confined to removal of the meter for recalibration and/or the replacement of components (and the entire meter when worn out). The cost of recalibration includes some means of running temporarily without a meter or the cost of hiring a replacement.

Where a steam meter is to be installed on a temporary basis, it is important to consider the logistics of its removal. For example, is it necessary to fit a new, flanged spool piece or can a plug be fitted to the pipework connection?

5 Types of steam flow meter

This section describes the various types of flow meter in common use in steam systems. For each type, a short explanation of how it works is provided, along with a summary of its advantages and disadvantages. The following types are discussed:

- Turbine meter
- Bypass or rotary shunt meter
- Orifice meter
- Variable area flow meter
- Spring-loaded variable area flow meter
- Simple Pitot tube
- Averaging Pitot tube
- Vortex shedding meter.

Table 1 in Section 7 provides a summary of their qualities.

Three main categories of meter are discussed in this section:

Turbine meters. These rely on the mechanical effect of flow to drive a turbine. Given the fixed geometry of the meter and its associated pipework, the speed at which the turbine rotates is proportional to the flow of steam.

Meters based on a system that measures the pressure differential between two fixed points. An orifice plate or Pitot tube arrangement can be used to create a measurable pressure differential.

Vortex shedding meters. These employ a component to disrupt the flow pattern and thus cause light pressure pulses with a frequency that is proportional to flow velocity.

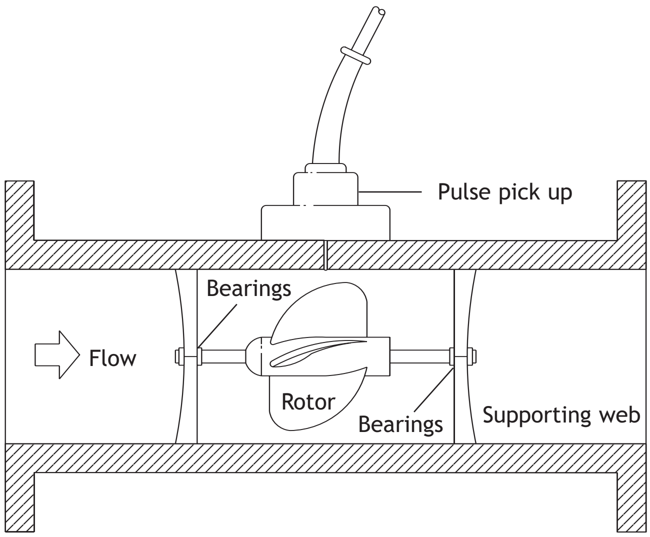
Choose the best meter for a specific application carefully. The wrong choice could be a complete waste of money!

5.1 Turbine meter

The turbine steam meter (see Figure 3) is probably the most simple design solution to flow measurement.

In the turbine meter, the rotor speed increases with higher flow. An electronic pulse is generated each time a blade of the rotor passes the sensor (the pulse pick up in Figure 3). Knowing the number of turbine blades, the frequency of the pulses determines the speed at which the turbine is rotating. The speed can then be related to the volumetric flow.

Figure 3 *Turbine steam flow meter*



A pulse pick up (a magnetic circuit that detects the passing rotor blades) is used to eliminate the vagaries of frictional loading imposed by a purely mechanical system. The pulse output is connected to a flow computer, enabling instantaneous and totalised flow to be measured. Steam pressure and, if required, temperature compensation are easily provided through the addition of appropriate transducers.

The components in a turbine meter have to endure the high steam temperature and little or no lubrication. In time, the blades will erode and the bearings will wear; these effects will cause a change in the meter's characteristics.

Any swirling action of the incoming flow stream, which will affect the accuracy of the meter, can be overcome by following the pipework geometry recommended by the manufacturer.

Advantages

- Good accuracy over a large turndown, although care is needed with the pipework geometry in which the meter is installed.

Disadvantages

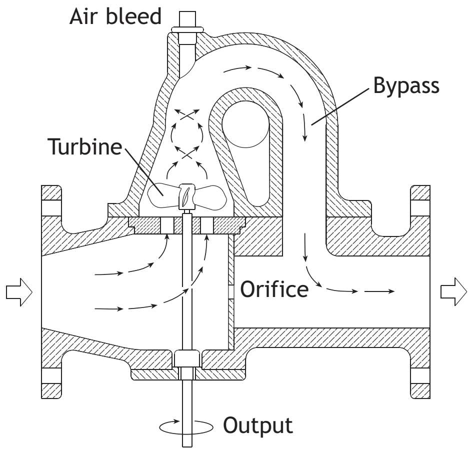
- Susceptibility of the bearings to wear and eventual failure
- Need for recalibration to compensate for bearing wear and rotor blade erosion.

5.2 Bypass or rotary shunt meter

This type was designed as simple mechanical alternative to the turbine meter. Although generally obsolete, many examples are still in service.

The rotary shunt meter (see Figure 4) uses an orifice plate to ensure that a proportion of the flow passes through the bypass port and thereby through the turbine. The turbine is connected mechanically to a counter, which allows a total flow count to be made over a period of time. The meter is normally supplied calibrated to the intended steam pressure. Recalibration is essential if the normal operating pressure changes in the line in which the meter is installed.

Figure 4 *Bypass or rotary shunt meter*



Advantages

- Simple mechanical means of providing total flow count.

Disadvantages

- Need for recalibration to compensate for wear
- Accuracy is adequate for many applications, although it is not precise
- Its simple design means it is not normally possible to provide pressure compensation. Hence, accuracy is reduced if the steam pressure varies
- Not usually available with an instantaneous flow display.

5.3 Orifice plate meter

This is probably the most commonly used type of meter on steam systems, though its popularity has declined with the availability of more advanced devices such as the vortex shedding and averaging Pitot meters.

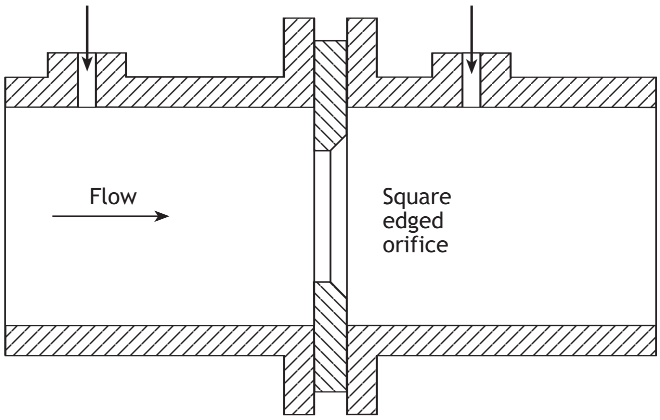
To understand how this type of meter works, it is necessary to consider what causes flow. The flow of a fluid from one place to another is due to a difference in pressure between the two places. For example, a boiler will supply steam to a process application only as long as there is a lower pressure in that application. If the pressures were equal, there would be no flow.

Along a length of pipe through which a fluid flows, there is a pressure gradient. The pressure is highest at the upstream end, and progressively reduces along the length of the pipe. The flow has a geometrically proportional relationship to this pressure differential; the volumetric flow rate is proportional to the square root of the pressure differential. Measuring the pressure differential across two fixed points along the pipe thus forms a basis for flow measurement. However, it would be impractical to measure the pressure differential between two remote points along a pipe. Therefore, the solution is to introduce a slight flow restriction at one point and to measure the pressure differential either side of that point.

Installing an accurately manufactured orifice plate into the steam pipework provides the basis of a simple, yet highly effective, steam meter (see Figure 5). The pressure tappings upstream and downstream of the orifice plate are connected through small bore pipes (known as impulse lines) to a device called a differential pressure (DP) cell (see Section 6.1) that

measures pressure differential. The pressure differential is interpreted by a flow computer (see Section 6.2), which allows either instantaneous or totalised flow to be calculated and displayed. The measured pressures (as distinct from the pressure differential) can also be used to provide automatic pressure compensation, thereby ensuring accuracy over varying flow conditions.

***Figure 5** Orifice plate meter*



When an orifice plate is installed in a horizontal pipe, it is necessary to position an additional small hole at the bottom of the pipe to prevent condensate accumulating on the upstream side.

The size of the orifice plate should not cause a substantial pressure drop and thereby impose a restriction to flow. Because of the square root relationship between flow and pressure differential, the turndown ratio of an orifice plate meter is restricted to 4:1 or perhaps 5:1. The orifice plate has to be sized to accommodate the maximum flow without introducing an unacceptable pressure loss; if the flow falls to a quarter, the pressure differential will fall to a sixteenth and be difficult to detect.

Flow through an orifice meter has to be smooth; any tendency for a churning or otherwise unstable pattern of flow is liable to disrupt the measured pressures (a DP cell is an extremely sensitive device). Installation usually requires a minimum length of straight pipe equal to 20 pipe diameters upstream and 10 pipe diameters downstream. For example, in the case of a meter installed in a 200mm line, the overall length of straight pipe required is 6 metres. This is not always practicable.

The orifice can erode, particularly affecting the square edge at its inlet. This reduces the pressure differential across the orifice, leading to under-reading.

Advantages

- Simplicity and physical strength
- Good accuracy throughout its turndown range
- Inexpensive to buy
- Does not require calibration (this is taken care of during manufacture).

Disadvantages

- Need to inspect the orifice regularly and to replace as necessary
- Limited turndown
- The orifice can buckle due to water hammer
- In horizontal lines, the additional hole can block due to scale or dirt. The consequent upstream accumulation of condensate or dirt then affects the meter's accuracy.

5.4 Variable area flow meter

This design, which is suitable for vertically upwards flow only, relies on the weight of the float counter-balancing the force of the flow passing through the metering unit.

The metering unit is a tapered length of pipe (see Figure 6). As the flow increases, the float moves to an area where the cross-sectional is greater. The cross-sectional area increases at all positions. For any given flow rate, there is a unique position at which the float will come to rest. The float unit is usually coupled magnetically to an external flow indicator. The geometry of the metering unit is such that there is a linear relationship between flow and float displacement.

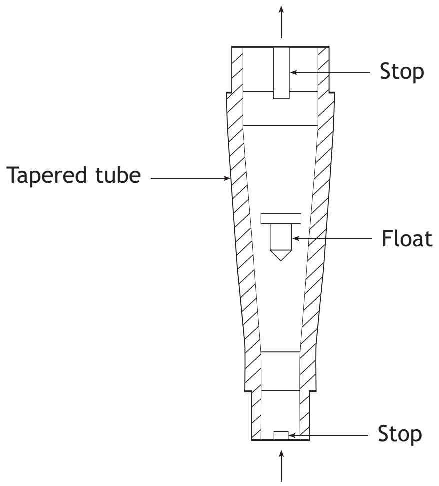
Advantages

- Simple design
- Reliable
- Better turndown ratio
- Constructed of materials able to withstand high pressures and temperatures.

Disadvantages

- Use restricted to vertically upwards flow (i.e. has to be mounted upright)
- Accuracy is only moderate.

Figure 6 *Variable area flow meter*

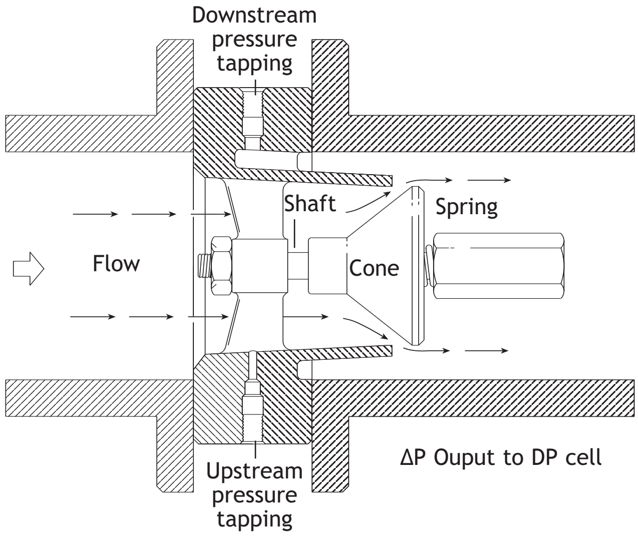


5.5 Spring-loaded variable area flow meter

The spring-loaded variable area flow meter is a development of the simple variable area meter. Its design (see Figure 7) incorporates a compression spring that acts instead of the mere weight of the float unit. Although the output can be taken from the position of the float, an alternative – and more accurate – flow measurement can be established from the pressure differential across the unit.

As with the orifice plate meter, the flow rate is proportional to pressure differential. The cone adopts a position according to pressure differential; if the flow increases, the cone opens to a wider setting. The overall effect is to stretch the pressure differential range through the available movement of the cone. Because of the square root relationship between flow and differential pressure, a fixed size of orifice only offers a limited turndown ratio of perhaps 4:1 or 5:1. However, the spring-loaded cone of the variable area meter means that the orifice size itself varies with flow. This substantially extends the useful operating range of the meter, providing a turndown ratio of 30:1 or better.

Figure 7 *Spring-loaded variable area flow meter*



Advantages

- Good accuracy
- High turndown ratio.

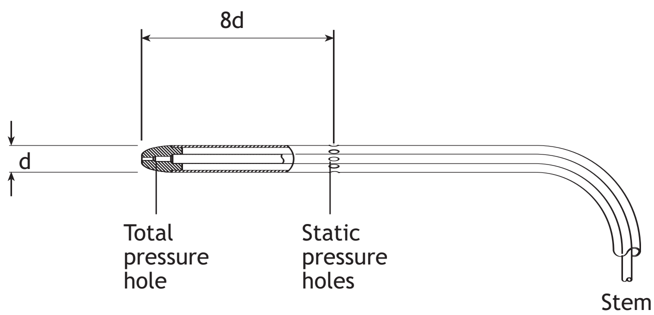
Disadvantages

- Susceptibility to wear, particularly if the steam is wet and/or dirty
- Recalibration (and ultimately repair or replacement) required.

5.6 Simple pitot tube

A simple Pitot tube consists of two coaxially mounted tubes (see Figure 8). The inner tube faces directly into the flow, while the outer one has its end blanked off and has perforations at a fixed point on its outside. The Pitot tube is inserted into a straight section of pipework.

Figure 8 *Simple Pitot tube*



The outer tube measures the static pressure in the pipe. The inner tube measures this pressure plus the additional pressure resulting from the force of the flow. The difference between these pressures is converted into a flow measurement.

Advantages

- Low-cost solution for large pipe sizes
- Minimal resistance to flow.

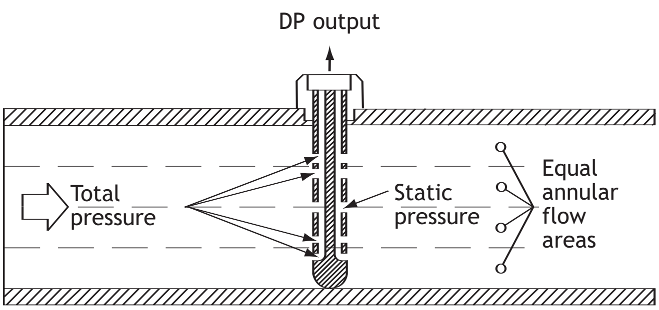
Disadvantages

- Low turndown ratio
- Has to be sited correctly to measure the average flow condition over the pipe cross-section
- Its small orifices are prone to blockage under dirty steam conditions
- Accuracy demands that it is installed in an area free from swirling or disturbed flow patterns.

5.7 Averaging pitot tube

This is a development of the simple Pitot tube, in which a small bar is mounted diametrically across the pipe. This bar has two internal pipes – one on the upstream side and the other on the downstream side (see Figure 9). These pipes have a number of ports, so that the average pressure across the pipe is measured.

***Figure 9** Averaging Pitot tube*



The ability of this meter to collect an average value over the cross-section of the pipe eliminates the need to locate it accurately in the precise centre of the pipe. However, the metering unit needs to be positioned accurately across the diameter of the pipe.

Both the simple and averaging Pitot tubes are subjected to the flow force on their upstream faces. However, whereas the simple Pitot tube measures the static pressure, the averaging Pitot tube experiences the suction effect on its downstream side. This enhances the pressure differential, extending the potential turndown ratio to 10:1 or more. Accuracy at low flows is limited by the characteristics of the selected DP cell.

The averaging Pitot meter is easy to install in existing pipework, requiring only a single socket to be welded to the pipe. In the case of large pipe sizes, an additional socket may be required to securely locate and stabilise the opposite end of the metering unit.

Advantages

- Low installation cost, particularly on large pipe sizes
- Minimal resistance to flow
- Reasonable turndown ratio
- Good accuracy and repeatability.

Disadvantages

- Has to be incorporated within an adequate length of straight pipe to eliminate disturbed flow patterns that lead to inaccurate readings.

5.8 Vortex shedding meter

The vortex shedding meter is different from the meters described previously in that it measures a flow phenomenon rather than flow itself.

When a fluid impinges upon an obstruction, it passes over it. As the flow leaves the obstruction, vortices develop. These vortices are formed in a rhythmic pattern, detaching first from one side of the obstruction then from the other. Each vortex has a slightly lower pressure than the surrounding fluid. The frequency with which the vortices are generated is proportional to flow velocity. By engineering the geometry of the flow obstruction, the vortex generation can be enhanced, thus enabling clearly defined vortices to be identified.

This phenomenon can be observed when watching a flag blowing in the wind. Once the wind is sufficiently strong, its passage over the flagpole generates vortices. These vortices pass over the flag, forming first on one side and then the other. The flag is drawn towards the lower pressure of each vortex and, characteristically, flutters. The frequency with

which the flag flutters is proportional to the strength (velocity) of the wind.

A vortex shedding flow meter consists of a flow obstruction, known as a bluff body, mounted vertically in a section of pipe (see Figure 10). The shape of the bluff body is engineered to generate strong vortices and the key element of its design is the flat or 'bluff' profile presented to the incoming flow (see Figure 11). It is usual for the section of pipe to be flanged or have a wafer pattern for clamping between flanges.

***Figure 10** Vortex shedding meter*

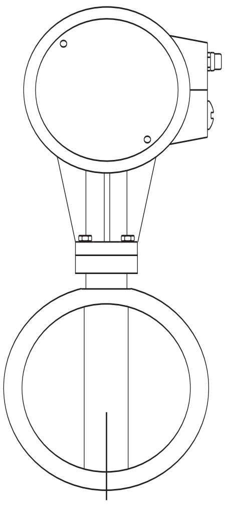
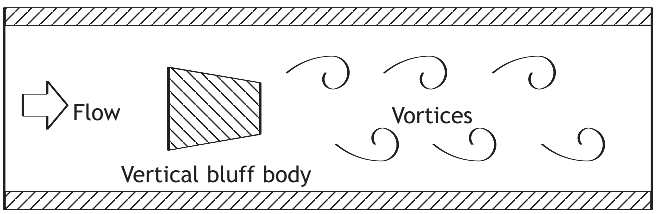


***Figure 11** Principle of the vortex shedding meter*



Either side of the bluff body is a pressure tapping that allows the pressure pulse produced by each vortex to be measured. These pressure tappings are connected to a measuring cell. Unlike the meters described previously, the differential pressure value is not significant. In a vortex shedding meter, it is the frequency of the pressure pulses that is important. This frequency is proportional to flow and can be reliably measured using a piezo sensor. Because the measured value has a direct relationship to flow (rather than the square root relationship of pressure differential measurements), a practicable turndown ratio of 20:1 can be achieved on steam systems.

Although the turndown ratio is high, the vortices at low flows will be weak and might not be read. The high flow end of the range may therefore be at a steam flow of perhaps 75 metres/second or even 100 metres/second. This is generally considered inappropriate for conveying saturated steam due to the high pressure drop over a significant length of pipe and attendant high velocities that may cause water hammer if remote from a separator. To achieve a good turndown ratio, it is often necessary to install a vortex meter within a section of reduced size pipe, which may further exacerbate pressure loss.

It is also necessary to ensure an adequate run of straight pipe either side of the meter to avoid any swirling flow patterns that would disturb the flow and give rise to incorrect readings.

Advantages

- Lack of moving parts means very reliable
- Good turndown ratio and excellent repeatability
- Pressure drop can be minimised if care is taken over the selection of the meter size
- Recalibration should not be necessary if the steam is clean and dry (the design of the bluff body means it can withstand wear without impairing the generation of vortices).

Disadvantages

- Need for long lengths of straight pipe (although if this is not possible, the percentage error can often be calculated)
- Possible resistance to flow at high flow rates
- Susceptibility to mechanical vibration (may be interpreted as flow values or even prevent effective operation of the meter).

6 Instrumentation and data handling

As well as the meter located in the steam flow (the primary element), a device will also be needed (the secondary element) to translate the information from the meter into a usable form and some form of processor to produce the information required. This processor may also receive pressure and/or temperature data for compensation calculations. This section considers:

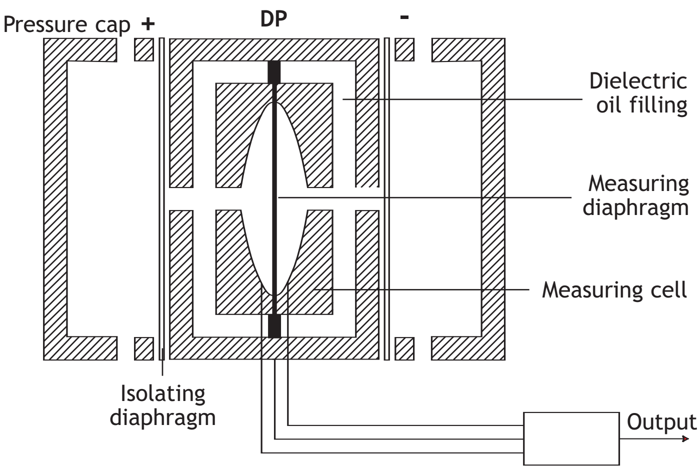
- DP cells
- Flow computers
- Multivariable cells
- Installation of impulse lines
- Data collection and analysis.

6.1 DP cells

Most of the steam meters described in Section 5 rely on the measurement of pressure differential using a secondary element known as a DP cell (see Figure 12). This changes the pressure signal to an electrical signal.

A simple DP cell is connected to both the upstream and downstream sides of the metering unit through small bore pipes known as impulse lines (see Section 6.4). These connect to chambers either side of a diaphragm, whose displacement is sensed by a load cell, and converted into a pressure differential value. This value is normally sent to a flow computer, usually using a 2-40mA dc signal.

***Figure 12** Principles of the DP cell*



6.2 Flow computers

The signal from the meter representing volumetric flow has to be converted into a flow measurement. Because steam is a compressible gas, it is necessary to know its pressure to determine the mass flow. This can be done in one of the following two ways.

Fitting a pressure transducer to the pipework upstream of the flow meter. The pressure transducer sends a pressure signal to the flow computer. This allows automatic compensation for the steam density on a continuous basis. However, the flow computer needs to be programmed so that it knows what the limit values of the transducer relate to and can interpret the output from the transducer correctly. For example, if using a 4–20mA transducer with a range of 0-1,000kPa(g) (0–10 bar(g)), it is necessary to program the flow computer to recognise that 4mA = 0kPa(g) and 20mA = 1,000kPa(g). Care must be taken not to confuse absolute pressure and gauge pressure values.

Using a fixed pressure value. When the steam pressure is controlled within close parameters, the flow computer can be programmed to use a fixed pressure value. For example, on a system operating at a pressure assumed to be fixed at 500kPa(g) (5 bar(g)), it is necessary to program 0mA = 500kPa(g) (0mA is the value obtained by the flow computer in the absence of a pressure transducer). It will probably be necessary to ascribe an arbitrary higher value to a 20mA signal.

In some cases, cost constraints may rule out the fitting of a pressure transducer, even though the steam pressure will vary within certain limits. While possible, the accuracy of any readings will be open to question.

Temperature compensation may also be required, although most steam flow computers are programmed to assume saturated steam conditions. Temperature compensation is usually only needed in situations where superheated steam could exist.

Once a flow computer has been programmed with information as to the meaning of the 4-20mA or pulse signal from the flow meter, the mass flow can be calculated, displayed and recorded. This programming is normally performed by the installer and is a relatively easy task.

It may be possible to enter an assumed dryness fraction into the flow computer. It is unlikely that

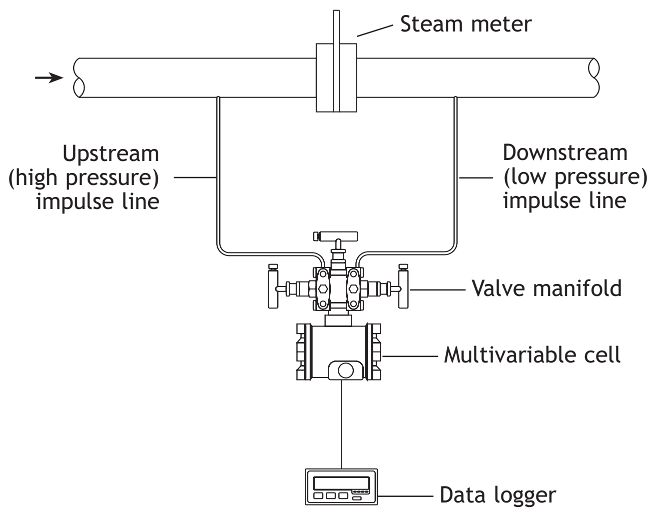
the steam will be perfectly dry and the ability to correct to, say, a dryness fraction of 97% gives improved accuracy.

Most flow computers are able to provide an instantaneous flow display, with the option to display totalised flow over a period of time. Although it is normal to display flow values in kg/hour, it may be possible to display them in energy terms such as kW or MJ.

6.3 Multivariable cells

The multivariable cell measures both pressure differential and absolute pressure, and applies the necessary corrections. This means that there is no need for a flow computer to calculate the steam density correction. In addition, the 4–20mA signal from the multivariable cell can be connected directly to, for example, a building management system or a data logging device. Figure 13 shows a typical arrangement of a multivariable cell.

Figure 13 *Application of a multivariable cell in steam metering*



However, a separate temperature signal is still required for superheated steam applications. Multivariable cells are now available with the facility to accept the input from a temperature transducer.

6.4 Installation of impulse lines

Impulse lines are the small bore pipes that connect the pressure tappings upstream and downstream of the meter to a DP or multivariable cell. A three-valve or five-valve manifold fits between the impulse lines and the cell. Figure 13 shows a three-valve manifold; a five-valve manifold additionally incorporates a drain valve for each impulse line.

Between the isolating valves is an equalising valve. This is required during the commissioning of the meter and following any maintenance work.

On steam applications, it is necessary to protect the DP or multivariate cell from steam temperature. This is achieved by filling the impulse lines with water. It is important that the static head of water is equal; otherwise there will be a pressure differential and a permanent offset from true and accurate readings.

The impulse lines should also be the same length and have equivalent geometry. Any residual differences may be zeroed at the DP cell.

6.5 Data collection and analysis

The collected data should be analysed to provide information to control energy costs and to identify potential opportunities for energy and carbon savings.

Although the steam metering unit may be supplying information to the data recording system continuously, the recorded values may not be continuous. The data may be sampled every few seconds or minutes or, alternatively, they may be collected continuously and a value recorded on the basis of an average over a period of, perhaps, a few minutes. Such compromises may not be significant where the main objective is to monitor total energy use. However, there are some instances where transient peak loads are important. In such cases, it is essential to be aware of any potential shortcomings in the quality of the recorded data.

Where the cumulative amount of steam used over long periods is required, the accuracy of the metering system is vital. An instantaneous error of ±2% may not sound critical, but the cumulative effect over the period of several months may indeed be significant.

The need for pressure and temperature compensation should not be ignored. Neither should steam quality; there is little point paying for the most expensive and accurate metering system if the results are degraded due to poor steam quality.

By analysing flow, it is possible to learn about the steam demand and to identify priority areas for improved performance and efficiency. For example:

- A consistent background flow might indicate poor insulation, which in turn is creating a continuous demand for steam
- Peak demands for steam may be identified as belonging to inefficient processes
- The highest steam-consuming processes/departments/buildings at a site can be identified.

But only once readings are available can any sensible action be taken.

Call the Carbon Trust Energy Helpline on 0800 58 57 94 or visit www.thecarbontrustenergy.co.uk/energy to obtain practical advice on how to reduce steam generation and distribution costs. Useful publications are listed in the *Other sources of information* section at the end of this guide.

Careful analysis of the collected data will yield opportunities for energy and cost savings.

7 Selecting a suitable flow meter

No steam flow meter can universally be described as the 'best'. The choice of meter generally necessitates a compromise between criteria such as accuracy, turndown ratio, repeatability, purchase price, installation cost and maintenance issues.

Each installation will have its own priorities, but it is essential to consider carefully:

- The application
- How the obtained measurements will be used
- The consequences of pressure loss caused by the meter.

The criteria covered in Table 1 should all be considered, although the order of importance will vary from one application to another. Table 1 is not intended to be definitive as products will vary between manufacturers and qualities such as available turndown ratio will depend on the application.

The following should be borne in mind when choosing a flow meter:

- Why the meter is being installed:
  - When measuring energy use by an individual cost centre, for example, turndown ratio may be important because of the need to measure small flows. If small flows exist for extended periods, their cumulative effect may be ignored by meters with a poor turndown.
  - A meter may sometimes be installed on a temporary basis to measure the true flow of steam to determine the appropriate size of new boiler plant. Under these circumstances, turndown ratio will be less important and low cost and ease of installation will prevail.
  - On other occasions, the constraints of existing pipework and/or availability of downtime may influence meter selection.
- Ensure that the pressure and temperature rating of the meter are appropriate for the application.
- If the flow parameters to be measured are not known, choose a meter with a large turndown ratio. Sizing the meter is one of the most difficult considerations. It makes little sense to fit a flow meter for the sole purpose of discovering the size of the meter that is actually required.
- Ask potential suppliers about how the two elements of the proposed metering system will behave in combination under low-flow conditions. For example, the primary element (the metering unit) may be capable of measuring over a substantial range, with diminished accuracy at very low flows. Other units may cease to provide any meaningful output below a certain flow. The secondary element (usually a DP or multivariable cell) may impose similar limitations. It is possible to combine a second, lower range cell on the same impulse lines, thus substantially increasing the turndown ratio and maintaining good overall accuracy.
- Do not rely on a boiler's maximum rated output when selecting a flow meter to measure the steam supplied by that boiler. Most shell boilers have sufficient stored water capacity to be able to deliver a significantly greater output than the maximum stated – albeit for a very short time, after which the boiler might even lock out due to low water levels. If there could be severe load swings, the flow meter may have to read higher flows than envisaged.
- When metering the flow to a specific application, inspect the valves supplying that area of the plant. Most control valves are marked with their maximum flow capacity. The Kv value[5] of a valve will help to determine the maximum steam flow through the valve into a specific plant area or to a certain process. This can be done by calculation or using a chart.
- Do not assume that because the steam pipework is of a certain size, the appropriate meter will be of equal size.
- Seek advice from meter manufacturers to ensure that the most appropriate meter is selected and that its installation provides the most favourable working conditions. New installations will usually offer the opportunity to incorporate a suitable unit in their design.
- Potential of wear and tear on the meter and the consequent need for recalibration.

[5] The Kv value or factor is the flow of water through a valve at 20°C in m3/hour with a pressure drop of 100kPa (1 bar)

Table 1 *Selecting a suitable flow meter*

Criteria	Turbine	Rotary shunt	Orifice plate	Variable orifice	Spring loaded variable orifice	Pitot tube	Averaging Pitot tube	Vortex shedding
Accuracy	Good	Moderate	Moderate	Good	Good	Good	Good	Good
Turndown ratio	10:1	<5:1	<5:1	30:1	30:1	5:1	10:1	20:1
Repeatability	Poor	Poor	Good	Moderate	Good	Good	Very good	Very good
Sensitivity to vibration	Low	Low	Low	Moderate	Low	Low	Low	Poor
Sensitivity to installation	High	High	High/moderate	Low	Low	Moderate	Moderate	High/moderate
Installation ease	Difficult	Moderate	Easy	Moderate	Easy	Very easy	Very easy	Moderate
Pressure loss	Moderate	Moderate	Moderate	Low	Low to moderate	Low	Low	Low to moderate
Recalibration	Frequent	Frequent	Frequent	Frequent	Infrequent	Infrequent	Infrequent	Infrequent
Purchase cost	Moderate	High	Low	Moderate	Moderate	Low	Low	Moderate
Installed cost	Moderate	Moderate	Low	Moderate	Moderate	Low	Low	Moderate
Maintenance cost	Moderate	Moderate	High	Moderate	Moderate	Low	Low	Low

8 Installation

To deliver accurate results, all steam flow meters should be installed according to the manufacturer's recommendations. It is not possible in this guide to comment on every type of meter, but some general considerations are given below.

Steam quality. There should be an adequate trapping arrangement upstream of the meter, which ideally should incorporate a separator (see below). If a strainer is incorporated in the piping system to protect the meter from dirt, this should be an acceptable distance from the meter to avoid disturbing the flow pattern.

Pipe size. To provide an acceptable turndown ratio, it may be necessary to install a smaller meter. This may require the pipework to be reduced in size, not only at the meter but also for a certain length either side of it. In such cases and where the meter is to be installed in a horizontal line, it is important to use eccentric reducers (rather than concentric ones) to prevent the accumulation of condensate.

Pipe length. A sufficient run of straight pipe both upstream and downstream of the meter is required.

Flow alignment. Some meters are susceptible to the swirling effect of flow after a bend. A longer upstream length of straight pipe or a flow alignment device (a 'flow straightener') may be recommended in such cases.

Gasket protrusion. Meters installed in flanged pipework require gaskets. It is important that these gaskets do not intrude into the pipework, otherwise flow may be disrupted and accuracy will suffer.

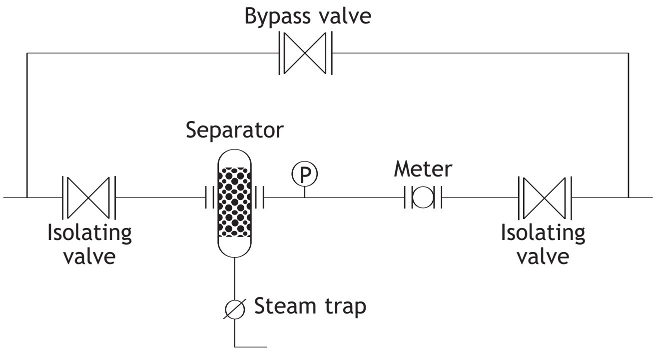
Impulse lines. These should be of equal length where practicable (see also Section 6.4).

Steam separators. Installing some form of separator or trapping point an acceptable distance upstream of a steam meter serves to:

- Protect it from damage due to water hammer
- Optimise the accuracy of the measurement by removing as much entrained condensate as is practicably possible.

Figure 14 shows a typical installation of a steam meter with steam separator, isolating valves and bypass valve.

***Figure 14** Typical steam meter installation*



For maximum reliability, accuracy and repeatability, follow the manufacturer's installation instructions.

9 Advanced water-level controls for boilers

The use of steam meters as part of the boiler control system is expected to increase with the need to develop the smaller, more efficient and more responsive steam boilers demanded by industry and other major steam users.

Recent years have seen a trend towards manufacturing physically smaller steam boilers. Reasons for this include:

- Commercial pressure on manufacturers to reduce production costs
- Production of smaller boilers uses less resources
- Smaller boilers have lower standing heat loss due to their reduced surface area.

Boiler plant installed today is generally sized to adequately meet the installed steam load and does not have the substantial spare capacity that would have been provided, say, 20 years ago.

However, smaller boilers have a reduced ability to meet sudden increases in steam load. When a boiler experiences a demand for steam, its pressure falls. If the load is particularly heavy, the pressure drop within the boiler is sufficient to cause spontaneous boiling of the boiler water to form flash steam. This is how a steam accumulator works. However, a boiler has insufficient stored water capacity to meet a sustained excessive load. As a result, the boiler water level becomes unstable and nuisance low-water level alarms or lockouts occur.

Advanced water-level controls are increasingly being fitted on boilers with a capacity of 5,000kg/hour and greater, particularly when the steam-using plant is known to be capable of imposing substantial transient peak loads. They usually consist of a steam meter, possibly augmented by a water flow meter. The information from these meters is integrated with the information obtained from the standard boiler water level measuring equipment.

- Where a steam flow meter is used in what is known as a 'two element' level control system, its purpose is to identify a sudden increase in the flow of steam from the boiler. This increase triggers the addition of more water to the boiler to compensate for its release as steam before the water level itself falls to a critical level. The boiler therefore operates in a more stable fashion
- Three-element water level control employs a steam meter to measure steam leaving the boiler as well as a water flow meter to measure the flow of water into the boiler. The difference is used to identify any disparity in these two flows, and the water level control valve is adjusted accordingly.

Recent developments in boiler controls have also included the use of steam flow as an additional element in burner control to match the burner firing rate to boiler load more precisely.

Other sources of information

Free publications from the Carbon Trust

Call the Carbon Trust Energy Helpline on 0800 58 57 94 or visit www.thecarbontrustenergy.co.uk/energy

- GPG369 *Energy efficient operation of boilers*
- GPG382 *Energy efficient operation of heat distribution systems*
- ECG066 *Steam generation costs*
- EGG092 *Steam distribution costs*
- GPG221 *Improving boiler energy efficiency through water treatment*
- GPG381 *Energy efficient boilers and heat distribution: choosing the best system for your site*
- GPG326 *Energy metering.*

Other useful publications

- BS 1042 *Measurement of flow in closed conduits*
- Spirax Sarco free online learning modules, accessed at www.spiraxsarco.com/learn/

Useful websites

The Carbon Trust
www.thecarbontrust.co.uk/energy

Enhanced Capital Allowances
www.eca.gov.uk

British Standards Institution (BSI)
www.bsi-global.com

Combustion Engineering Association (CEA)
www.cea.org.uk

Climate Change Levy
www.hmce.gov.uk

Climate Change Agreements
www.defra.gov.uk/environment/ccl/index.htm

Glossary

Absolute pressure	The pressure measured from a baseline of a perfect vacuum. Denoted by (a) after the unit of pressure. Absolute pressure = Gauge pressure + Atmospheric pressure.
Accuracy	A measure of a meter's performance in indicating a correct flow rate value against a 'true' value obtained by extensive calibration.
Condensate	The pure water formed as steam condenses.
Differential pressure	The difference between two pressures.
Dryness fraction	A measure of how much water is entrained in the steam.
Flash steam	The steam produced when the pressure of hot condensate is reduced.
Gauge pressure	The pressure measured from a baseline of atmospheric pressure. Denoted by (g) after the unit of pressure. Gauge pressure = Absolute pressure – Atmospheric pressure.
Latent heat	Heat that changes the state of a substance (e.g. water into steam) with no accompanying temperature rise. Also known as the specific enthalpy of evaporation.
Repeatability	The ability of a meter to indicate the same value for an identical flow rate.
Sensible heat	The rise in temperature of a fluid as a result of the addition of heat. Also known as the specific enthalpy of water.
Steam separator	A device used to remove the entrained water droplets from wet steam.
Steam trap	An automatic device to allow the discharge of condensate from pipes or plant as it is formed.
Superheated steam	Steam where sensible heat has been added to increase its temperature above its boiling point.
Turndown ratio	The range of flow rates over which a meter will work within the accuracy and repeatability tolerances given. It is expressed as the ration between the maximum and minimum flow rates.
Water hammer	The result of condensate being pushed down pipes as solid slugs by steam pressure.

Notes

Tel 0800 58 57 94

www.thecarbontrust.co.uk/energy

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